IMPROVING THE INDOOR AIR QUALITY (IAQ) THROUGH APPLICATION OF THE AIR CLEANING TECHNOLOGIES FOR OFFICES BUILDING SIMULATED IN ENVIRONMENTAL CHAMBER

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DEDICATION

In the name of God, The Most Gracious, The Most Merciful.

To my mother, my father soul, my family and my friends.

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ABSTRACT

Indoor air quality (IAQ) is very important issue in residential and commercial buildings, because human spend almost 90% of their life indoor. IAQ problems effect on the health of the occupants, and lead to reduction of the efficiency and output in workplaces. The main objective of this study is to improving the (IAQ) and to reduce energy consumption in offices building, through experimental and simulation investigation. The method used in this study was by using environmental chamber to represent the real office. The results of the experimental were validated the simulation. The chamber was modified by installing two mechanical filters with low pressure drop; minimum efficiency reporting value rate 13 (MERV 13) and activated carbon filter (ACF) on the air handling unit. The IAQ parameters which include temperature, relative humidity, air velocity, air flow rate, pressure drop, CO_2 concentration and particle matters PM $_{10}$ and PM $_{2.5}$ concentration for upstream and downstream were considered in this study. These variables were measured inside the chamber using IAQ devices and these data were used as an input data for simulation by using ANSYS 16.1 software. The simulation generated the air distribution via air velocity, temperature, CO_2 concentration and the particle distribution in the room. The results from experiment showed good agreement for combining filters efficiency value from 86.20% to 84.60% and from 86% to 82.35% for PM $_{10}$ and PM $_{2.5}$ particle removal respectively during occupied period. The CO_2 concentration decreased during the measurement period from 816 ppm to 700 ppm and the distribution was in the acceptable range compare with ASHRAE standard 55-2004 and Malaysian industry code of practice on IAQ. Also, the validation with simulation showed below 10% error ratio compare with experiment results. The significance of study is to balance between enhancing thermal comfort inside workplace and (IAQ) for occupants, leading to reduction of energy consumption.

ABSTRAK

Kualiti udara dalaman (IAQ) adalah isu yang amat penting dalam bangunan kediaman dan komersial, kerana manusia menghabiskan hampir 90% daripada kehidupan mereka di dalam bangunan. Masalah IAQ memberi kesan kepada kesihatan penghuni, dan membawa kepada pengurangan kecekapan dan output di tempat kerja. Objektif utama kajian ini adalah untuk meningkatkan (IAQ) dan untuk mengurangkan penggunaan tenaga di dalam bangunan pejabat, melalui siasatan ujikaji dan berangka. Kaedah yang digunakan dalam kajian ini adalah dengan menggunakan sebuah bilik bagi mewakili pejabat sebenar. Hasil uji kaji telah disahkan simulasi. Bilik eskperimen tersebut telah diubahsuai dengan pemasangan dua penapis mekanikal dengan kejatuhan tekanan yang rendah; minimum laporan kecekapan kadar nilai 13 (MERV 13) dan penapis karbon teraktif (ACF) pada unit pengendalian udara. Parameter IAQ iaitu suhu, kelembapan relatif, halaju udara, kadar aliran udara, kejatuhan tekanan, kepekatan CO_2 dan kepekatan huluan dan hiliran zarah PM_{10} dan $PM_{2.5}$ telah dipertimbangkan dalam kajian ini. Pembolehubah diukur dalam bilik eksperimen dengan menggunakan peranti IAQ dan data ini telah digunakan sebagai data input untuk simulasi dengan menggunakan perisian ANSYS 16.1. simulasi menjana peredaran udara di dalam bilik melalui halaju udara, suhu, kepekatan CO_2 dan pengedaran zarah. Keputusan eksperimen menunjukkan kesesuaian yang baik untuk menggabungkan penapis bagi penyingkiran zarah PM10 dan $PM_{2.5}$ dengan nilai kecekapan 86.20%- 84.60% dan 86%-82.53% masing-masing semasa berpenghuni. Kepekatan CO_2 menurun dalam tempoh pengukuran dari 816 ppm kepada 700 ppm dan peredarannya adalah dalam julat yang boleh diterima jika dibandingkan dengan standard ASHRAE 55-2004 dan Kod Praktis Industri (IAQ) Malaysia. Pengesahan simulasi juga menunjukkan nisbah ralat di bawah 10% berbanding dengan keputusan eksperimen. kepentingan kajian, adalah keseimbangan antara meningkatkan keselesaan terma di dalam tempat kerja

dan kualiti udara dalaman untuk penghuni, yang membawa kepada pengurangan penggunaan tenaga

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LIST OF SYMBOLS AND ABBREVIATIONS

ACF	Activated carbon filter
Ag	Silvar nano
AHU	Air handling unit
ASHRAE	American society of heating refrigeration and air conditioning engineers
CADR	Clean air delivery rate
CO	Carbon monoxide
CO2	Carbon dioxide
COP	Coefficient of performance
COV	Constant air volume
DV	Displacement ventilation
EAC	Electrostatic precipitation filter
EBC	Exhaled breath condensate
EPA	Environmental Protection Agency
ESP	Electrostatic precipitator
F7	Fiber glass filter
FBF	Fiber bundle electret filter
GAC	Granular activated carbon
GF	Glass fiber filter
HEPA	High efficiency of particulate air
HVAC	Heating ventilation and air conditioning system
IAQ	Indoor air quality
IEQ	Indoor environment quality
IG	Ion generator
l/s/p	Liter per second per person
MERV	Minimum efficiency reporting value
MV	Mixing ventilation

NO_2	Nitrogen dioxide
PEF	Peak expiratory flow rates
PF	pre-Filter
PH	Acidic and basic level
PM	Particle matter
PMV	Predicted mean vote
PPD	Predicted percentage dissatisfied
PV	personalization ventilation
SOA	Secondary organic aerosol
UFP	Ultrafine particles
UV	Ultraviolet
VOC	Volatile organic compounds

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CHAPTER 1

INTRODUCTION

1.1 Overview

Poor indoor air quality is a vital issue around the world due to its significant impact on human health and work productivity. This chapter discusses the indoor air environment, thermal comfort and ambient air pollution. The chapter covers the problem statement, the objectives of the study and the scope of the research. Finally, the research question and significance are described.

1.2 Background of study

Poor indoor air quality (IAQ) is caused by indoor contaminates such as particle and gaseous pollutants. Studies have shown that people are more susceptible to diseases caused by polluted air in homes and offices rather than outdoors (Yu *et al*., 2009). Indoor areas enable possible pollutants to build up more than open spaces do. The main factors that contribute to indoor environmental quality (IEQ) are the thermal comfort, indoor air quality, acoustic comfort and lighting (Ncube & Riffat, 2012). The indoor air quality refers to the air quality within and around the buildings, that include the thermal comfort such as temperature, relative humidity, airflow rate, air velocity, occupants clothing, activity levels and occupancy in the area. These factors are addressed through indoor air environment to achieve thermal comfort and IAQ. Research has shown that there are health problems associated with poor IAQ (Niu, 2004). According to EPA (1995), indoor air pollutants comprise contents that come from dust, smoking, mold and bacteria, including all gases emitted by buildings, as

well as by equipment in buildings (Md Yusof, 2011). One of the important tasks of air conditioning system is providing thermal comfort for occupants.

The accepted desired indoor air by the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) Standard 62.1.2007 as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed to this situation express disaffection (Md Yusof, 2011). The main source of this pollutant is in the ambient outdoor air, which is naturally in the form of gases, multiple solid and liquid. They are produced mainly from fuel combustion, gases and particles as a result of the biological materials and chemicals used in the pesticides as well as sources of chemical reactions, dusts and bacteria (Ncube & Riffat, 2012).

The importance of IAQ to human health can be observed in work productivity. The usage of air-cleaning technology can effectively increase the thermal comfort by increasing the ventilation rates which may proportionally consume more energy. However, the air cleaning technology affect the thermal comfort by controlling the fresh air and air temperature which depend on filter rating. Moreover, it also affects the air quality by controlling the air contaminants. The quality of the indoor environment has a direct impact on the occupants, user productivity, referring to the fact that more than 80% - 90% of people spend their time indoors (Graudenz *et al*., 2005; Long, Suh, & Koutrakis, 2000; Zomorodian, Tahsildoost, & Hafezi, 2016). This implies that the indoor environment it is very important to human health and work. Temperature, humidity, air exchange rate, air movement, ventilation, particle pollutants, biological pollutants, and gaseous pollutants are all factors affecting the indoor environment (Graudenz *et al.*, 2005).

According to Nassif (2012) the use of heat, ventilation and air conditioning (HVAC) system in offices are employed in order to improve thermal comfort for the equipment and occupant. Air filters which are part of HVAC systems are adopted for their relevance and can never be over emphasized in the issues of improving indoor air quality.

The resuspension of the particle during working hours from indoor surfaces can be ensured by increasing the particle matter (PM_{10}) mass concentration together with a high number of particle sizes of more than 1 μm (Chatoutsidou *et al*., 2015).

During teaching hours the indoor/outdoor ratios measured with filter were compared with those measured without filter to assess the ability of the F8 filter to enhance the indoor air quality (Zee, & Janssen, 2017).

Azimi (2014) presented the findings of a study conducted on the particle removal efficiency of ultra-fine and PM $_{2.5}$ by using MERV filters. The study explained that all rating filters from MERV 5-16 to HEPA, were characterized by the filtration efficiency with percentage values ranging from 2% to 21% to 99%. This study shows that MERV filter alone cannot be reliable for the removal of ultra-fine particle and PM $_{2.5}$. The variations of energy and air quality impact of high-MERV filters were a lot of smaller at fouled condition. Nonetheless, high MERV filters still offer advantages to air quality. In terms of energy consumption, the use of high efficiency filters to treat contamination causes high energy consumption (Zaatari, Novoselac, & Siegel, 2014). In addition to providing thermal comfort in buildings, HVAC system contributes significantly to improving indoor air quality. Since the ventilation system falls within the air handling unit (AHU) this shows the importance of air conditioning system in supplying good quality indoor air (Zuraimi, Magee, & Nilsson, 2012).

Many technologies have been developed and used but a systematic assessment of these technologies is not widely available (Y. Zhang *et al* 2011).

1.2.1 Air cleaning technologies

Pollution may come from indoor or outdoor sources. Removing or reducing this pollution using ventilation, but the ventilation is not enough to removing all pollution. Air cleaning technology can remove more pollution than ventilation. These technologies include mechanical filters, electronic filters, absorption system, photocatalytic oxidation technology, ultraviolet germicidal and many types of packaged stand-alone or combination.

1.2.1.1 Combination filter (multi filters)

The multi filters is a method that uses two types of filters (pre-filter and final filter). This technology is used to remove particles and gases, specifically in the

applications context that deals with pollution caused by tobacco, dust, smoke and pollen. Malaysia has a high amount of smoke and dust that originate from factories and industrial areas. Therefore, the use of combination filters method can help to achieve high IAQ with low energy consumption.

1.3 Problem statement

Global warming and high pollution rates, especially in big cities and towns, challenge outdoor air and environment. Contaminations of the air by gases and particles also affect the IAQ. Poor IAQ causes many problems for human beings and these problems can cause health problems, reducing their efficiency and output at workplaces. Health problems such as asthma and pulmonary inflammation that lead to low attendance level, which affects productivity. The effects of these health challenges on productivity may in increase, considering that people sometimes spend more than average hours of their daily time in the workplace environment and breathing indoor air throughout their stay.

Malaysia has become an industrial country. Factories and manufacturing processes consume high energy and produce emit vapours as well as production waste. This affects the environment and in turn increases pollution level. This pollution may include nitrogen dioxide, carbon dioxide and sulphur dioxide (Leman, 2011). These pollutants have negative effects on the air quality, especially in the office environment. The negative effects are transferred to the indoor office environment and decrease the indoor air quality.

The energy consumption in Malaysia has significantly increased for the last 50 years. Most of the consumption is found in an office building. Office buildings consumes equivalent to 57% of the whole consumption rate (Saidur, 2009). The air conditioning systems are the highest consumer of the energy in office buildings. According to Li (2012), those systems consume 16% to 50% of electric power. The use of air conditioning system increased from 13251 units in 1970 to 253399 units in 1991, and is expected to reach 1.5 million in 2020. The energy consumption of air conditioning systems (AC) has significantly increased from 1237 GW/hr in 1999 to almost 2277 GW/hr in 2009 and it is predicted to reach 3055 GW/hr in the near future.

Based on the geographical location and statistical data, Malaysia is described as characterized by a humid climate with average temperature between 20 ºC to 32 ºC. Humidity has an effect on thermal comfort, which is part of IAQ in offices. In addition to the factories and manufacturing, energy consumption rates, are affected by electric equipment and climate. The IAQ is also challenged by other factors in the internal workplace, which are, ventilation, human, equipment, furniture and buildings materials.

Many attempts and methods have been applied to achieve good and acceptable IAQ and reduce energy in office buildings. Among the methods used are filtration, air-cleaning, ventilation and combined methods. The combination method was used by Bekö *et al*. (2009), utilizing the F7 bag type, which included activated carbon to remove particle pollution and ozone. This method was also used by Waring, and Corsi (2008), which deployed electrostatic precipitant (ESP) with activated carbon filter to remove large particle and ozone. A study using ESP and media filter pre filter for the removal of the fine particle was initiated (Zuraimi, 2009). In addition Gallego *et al*. (2013) used activated carbon filter with HEPA filter and other pre-filter to remove VOC and ozone. However, all these methods focused on particle, VOC and ozone removal. VOC and ozone removal are not effectively removed in all gas removal besides particles such as carbon monoxide, carbon dioxide and odours. It has been observed that Malaysians are exposed to the smoke from factories and automobile transportation systems, as well as haze. Thus this indoor air quality in the workplace is obviously affected, and the consequence to persons and environmental health has necessitated this research in an attempt to improve air quality and reduce the energy consumption rate in the Malaysian office building facilities.

1.4 Objectives of the study

The main aim of this research is to improve IAQ in Malaysian office buildings. The objectives of this study are:

1. To improve the indoor environmental comfort through air cleaning and controlling the indoor and outdoor contaminants. Thus, the combination filter was selected.

2. To assess the combination method that is characterized as high efficiency in the removal of pollutants. Removal of pollutant able to enhance the indoor air quality.
3. To assess the energy consumption in offices after using a low-pressure drop filter (less than 50 pa) with conventional filtration. However, balance between filtration efficiency and reduction of pressure drop must be considered.
4. To simulate the process of the air distribution and contamination using CFD modelling for validation purpose.

1.5 Scope of the study

Many technologies and methods have been developed to improve indoor air quality exposure in an office building. However, this study concentrated on:

1. Human health, comfort working environment.
2. Application of air filtration as well as air cleaning technologies in an office building environment.
3. This study focused on the gas pollution and particle concentration (PM_{10}, $PM_{2.5}$ and CO_2 removal).
4. The emphasis of the study was on the development of techniques to improve IAQ and recommending a practical way for Malaysians to ensure quality compliance based on ASHRAE standard 62.1-2010 and Malaysian standard (industry code of practice on indoor air quality 2010).
5. The importance of IAQ in the industrial state in a tropical climate was discussed.
6. This study also, focused on thermal comfort inside an office to ensure that the temperature, relative humidity; mean radiant temperature and air velocity as recommended from ASHRAE standard 55-2004 were acceptable by the occupants.
7. Furthermore, this study is more concerned with conservation of the energy in the office building environment by focusing on filter pressure drop.
8. The study focused on the experiment validated the simulation using ANSYS fluent 16.1. v. Ultra-fine particle and other gas pollution issues were beyond the scope of this thesis.

1.6 Research questions

1. How effective are these filters (combination filters) for protecting the occupants of offices against all pollutants?
2. Does the tropical climate any effect on the air quality in office buildings?
3. How can we achieve enhanced indoor air quality and energy saving at the same time?

1.7 Significance of the study

This study examined the areas of human health and indoor air quality (IAQ) in workplaces especially in office buildings. An office building is the context in which occupants can be exposed to long-term period of polluted air contamination and the quality level of indoor air is poor. The above situation can lead to discomfort, diseases and unsatisfied feelings that will definitely affect the human beings in such office areas, thus affecting the work quality and productivity of the worker (Ali *et al*., 2013). This study proposed some level of improvement on human health through enhancing air quality. Human health in workplace has been the main concern in most recent studies conducted in this field. Human health can affect productivity and the overall outcomes of any organization. In addition, the results from this study can help reduce the process expenses through energy saving. Particles removal will be more effective and can be enhanced through the use of filtration devices of high quality and efficiency. The use of this type of high efficient particle removals will increase power consumption. This is because filters come with packed high density leading to an increase in the resistance of airflow, which in turn requires extra power to compensate for pressure drop (Zuraimi & Tham, 2009). Consumption of energy in many Southeast Asian countries has been enormously increasing. Temperature and humidity control are adopted using air conditioners to improve indoor air quality for the occupants in buildings. Energy requirement, particularly a persistent and absolute request of air conditioner leads to increase of electricity demand for cooling in hot-humid climate nations (Daghigh, 2015). However, redeemable energy is a significant issue due to the high economic challenges under the new worldwide era of the energy challenges. Therefore, this study aimed to balance between enhancing

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